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The Role of Timber Bridges in the Road System of Western Australia

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1. INTRODUCTION

There are approximately 2 300 road bridges in Western Australia with a total deck area of 414 240 m^2. Until the discovery of gold towards the end of the nineteenth century settlement in Western Australia was confined almost entirely to the South West of the State where good quality hardwood was plentiful and timber was used exclusively in the construction of bridges until the 1920's. The use of timber has continued in this area of the State and timber bridges are still being constructed on all classes of road. The distribution of timber and other types of bridges on the various classes of roads is shown in Table I.

The amount of timber bridging constructed in recent years as a percentage of total bridge deck area has declined, mainly because new bridge construction has been concentrated in the north of the State and in the Perth Metropolitan area where steel and concrete are now used exclusively. Despite this 44% of total bridging in Western Australia is still timber and therefore comprises a very significant part of the total bridge asset.

2. HISTORY OF TIMBER BRIDGE CONSTRUCTION

2.1 The Convict Era 1850-1886

Up until 1850 less than ten bridges of any size were built in the colony. In June 1850, following a request by the settlers to the British Secretary of State, the first shipload of convicts arrived and were followed in December 1851 by the 20th Company of Sappers and Miners. The arrival of the convicts and the detachment of Royal Engineers marked the start of real progress in road and bridge construction in the colony. In the twelve years up to 1862 there was a convict labour force of approximately one thousand men and in that time they were responsible for the construction of 239 bridges, 543 culverts and 563 miles of road. This was in addition to the many public buildings they constructed.

During this period the design of bridges became standardised. Main spans over permanent water were generally 30 feet long and constructed using Queen Post trusses. Approach spans were 15 feet long, often using round timber stringers. The substructures consisted of driven round timber piles supporting a framework of heavy timber to carry the superstructure.

2.2 The Public Works Department Era 1886-1926

The convict system was disbanded in 1886 and construction of bridges on public roads became the responsibility of the Public Works Department. The designs for timber bridges were standardised even further and became less

TABLE I

DISTRIBUTION OF BRIDGES IN WESTERN AUSTRALIA

	ROAD CLASSIFICATION							
TYPE OF BRIDGE	National Highways		State Highways and Main Roads		Secondary and Unclassified Roads		Totals for all Roads	
	No of Bridges	Deck Area m^2	No of Bridges	Deck Area m^2	No of Bridges	Deck Area m^2	No of Bridges	Deck Area m^2
TIMBER	16	5 350	319	67 010	1 251	111 550	1 586	183 910
STEEL & CONCRETE	68	25 280	241	152 240	386	52 810	695	230 330
ALL BRIDGES	84	30 630	560	219 250	1 637	164 360	2 281	414 240

elaborate than some of the earlier bridges. They were mostly founded on round timber piles driven into the river bed but by this time development was moving away from areas of natural forest and masonry piers were used where timber was scarce. The superstructures consisted of 12 inch by 6 inch sawn timber stringers spaced 3 feet apart and spanning 20 feet. The deck was formed by transverse deck planks spiked or nailed to the timber beams. These bridges were designed to carry a six and two-thirds ton axle load.

2.3 The Main Roads Department Era 1926 - Present Day

In 1926 a Main Roads Board was formed to take over responsibility for public roads from the Public Works Department and in 1930 this became the present Main Roads Department. Bridge loading was initially increased from a six and two-thirds ton axle load to a 10 ton axle load by reducing spans from 20 feet to 15 feet, increasing the size of sawn timber stringers to 12 inch by 7 inch and reducing their spacing to 2 feet. In 1928 the Department made a major change in the design of timber bridges by replacing sawn timber stringers with round timber stringers having a mid-span diameter of 18 inches. This enabled spans to be increased to 20 feet but the design load remained a 10 ton axle until 1945.

In 1945 the American AASHO loading of a 20 ton truck (HS20) was adopted as standard and this required another change in design. The mid-span diameter of round stringers was increased from 18 inches to 21 inches and the size of sawn timber halfcaps which support the stringers at the top of driven piles were increased from 12 inches by 6 inches to 14 inches by 7 inches. This design has remained in use up to the present time and has proved adequate to carry the current T44 and A10 highway loadings introduced by the National Association of Australian State Road Authorities (NAASRA) in their Bridge Design Specification of 1976.

2.4 Early Bridges Over The Swan River

Two major timber bridges were built over the Swan River during the early years of the colony, one at the Perth Causeway and the other at North Fremantle. Both are of interest and illustrate the ease with which timber bridges can be modified to suit changing traffic requirements.

2.4.1 Causeway Bridge

The site chosen for the first Causeway Bridge was the Causeway Flats, a wide shallow section of the Swan River at the eastern end of Perth where a number of channels flowed between low islands. Work commenced on two low level structures spanning the main river channels in 1840 and was completed in May 1843. A drawing prepared in 1839 by the Surveyor General, J S Roe shows each channel bridged by two 30 feet span Queen Post trusses but few other details are recorded.

The bridge was overtopped by a large flood in 1862 and parts of the superstructure were washed away. The bridge was then reconstructed by raising the deck several feet and providing a third bridge. A detail of one of the Queen Post trusses used in this work is shown in Figure 1.

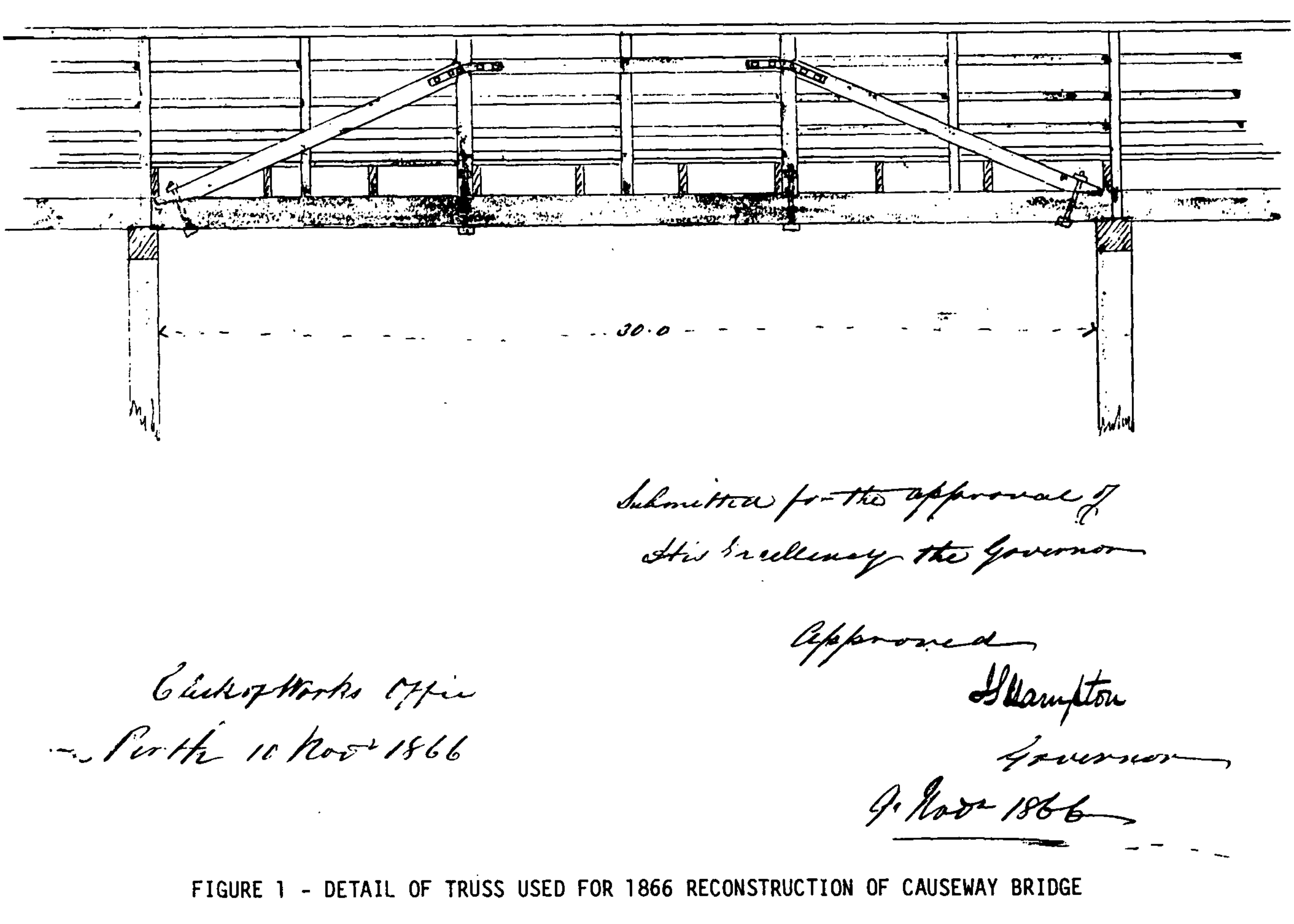

FIGURE 1 - DETAIL OF TRUSS USED FOR 1866 RECONSTRUCTION OF CAUSEWAY BRIDGE

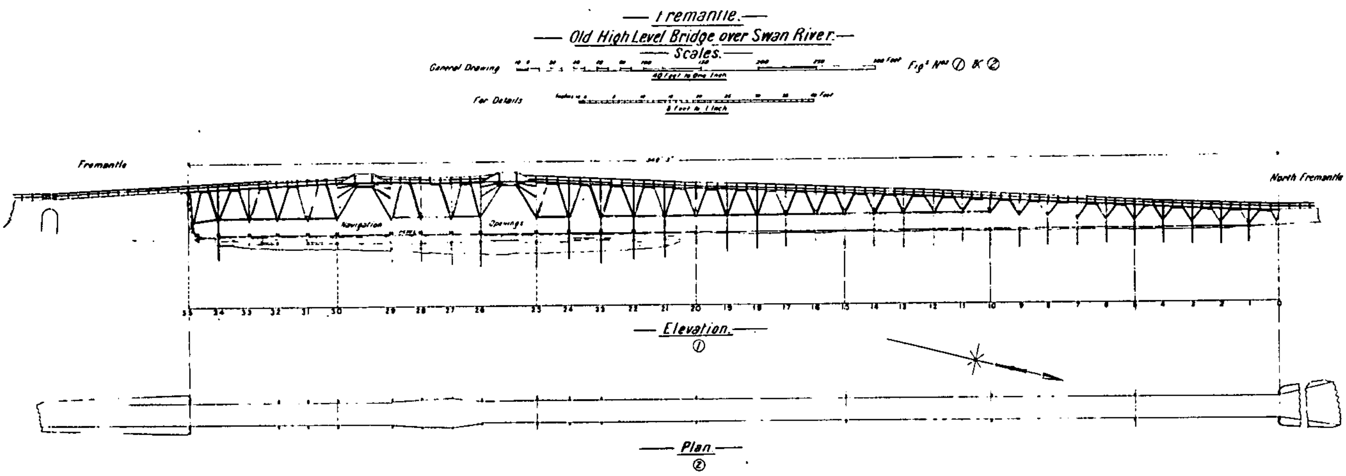

FIGURE 2 - NORTH FREMANTLE BRIDGE

The reconstructed Causeway crossing was opened in November 1867. It was widened in 1903 to carry tram lines on the upstream side and a further 10 feet widening was added to the downstream side in 1933. The timber structure was finally replaced by the present steel and concrete composite structure in 1952, after a total life of 109 years.

2.4.2 North Fremantle Bridge

The largest of the early timber bridges and the one most difficult to construct was the North Fremantle Bridge which was commenced in May 1863 and opened in November 1867. It was the last major bridge to be built using convict labour. The bridge had a total length of 940 feet and consisted of two navigation spans each of 45 feet and 33 other spans varying between 25 feet and 26 feet in span. The width of the roadway on the bridge was 18 feet and at the navigation spans the bridge was 44 feet above high water level. An elevation and plan of the bridge is shown in Figure 2.

The bridge was founded on 319 timber piles and except for the navigation spans, these were braced longitudinally approximately 14 feet above high water level. The junction between this bracing and the piles was then used as springing point for sloping props which supported the deck superstructure at the third point of each span. At the navigation spans the superstructure was stiffened with two Queen Post trusses projecting above the deck on each side of the bridge. This was a standard type of construction used in the colony at that time.

In the early 1890's the bridge was reported to be unsafe and in 1892 a load limit of 1 1/4 tons was placed on the structure. A wider bridge was built on the downstream side in 1898 but at a much lower level and the old bridge was closed to all except pedestrian traffic. In 1908 the local authority wished to extend the Fremantle tramway system across the river to North Fremantle but the newer low level bridge was at the wrong level. A careful underwater inspection was made of the old high level bridge and out of the 319 piles 306 were sound and only 13 had some defect. The superstructure of the old bridge was therefore cut down to remove the hump and the bridge widened to carry road traffic as well as trams. The low level bridge was removed and the old high level bridge continued in service until 1939, when it was replaced with the present timber bridge, a total life of 73 years.

3. CURRENT STANDARD PRACTICE

3.1 Standard Design

The standard design of timber bridge built in Western Australia has been evolved over many years and essentially consists of a series of simply supported spans connected by a continuous deck. A cross-section of the deck together with an elevation of the pier is shown at Figure 3 and a longitudinal elevation and section is shown at Figure 4.

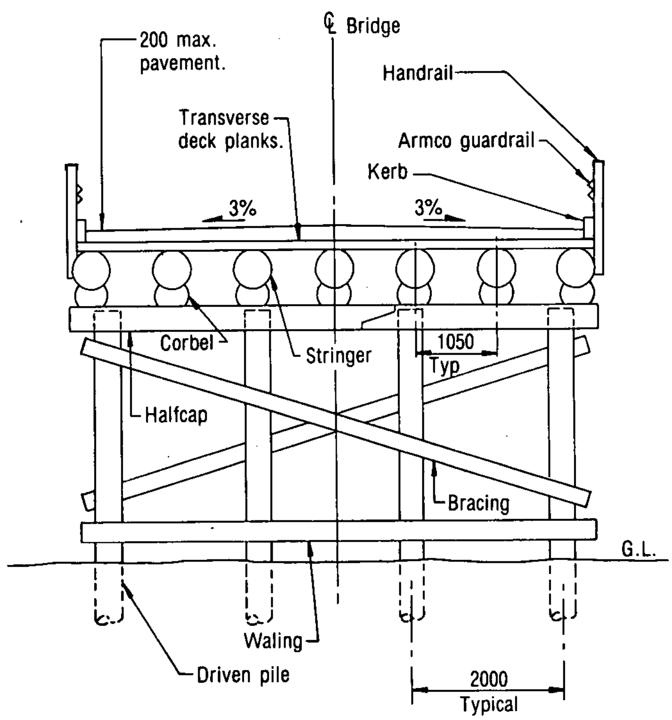

FIGURE 3 - CROSS-SECTION OF STANDARD TIMBER BRIDGE

3.1.1 Substructure

The substructure normally consists of driven round timber piles connected into a pier by horizontal sawn timber halfcaps which support the stringers and corbels. Pile dimensions are required to be within the following limits:

Crown diameter 300mm min to 400mm max
Butt diameter 500mm min to 700mm max

Where piles in a pier extend more than 3.0 m above ground lateral bracing is provided

consisting of horizontal walers and diagonal braces. At abutments the piles are sheeted with timber to retain backfill in the approach embankments as shown at Figure 5. This sheeting is susceptible to termite attack and it is now standard practice to treat the adjacent fill with a termidicide such as Aldrin or Heptachlor.

At abutments the stringers are seated directly on the halfcaps but over piers a short length of round timber known as a corbel is placed across the two halfcaps to support adjacent stringers from each span. This form of construction minimises differential movement between stringers of adjacent spans and provides some

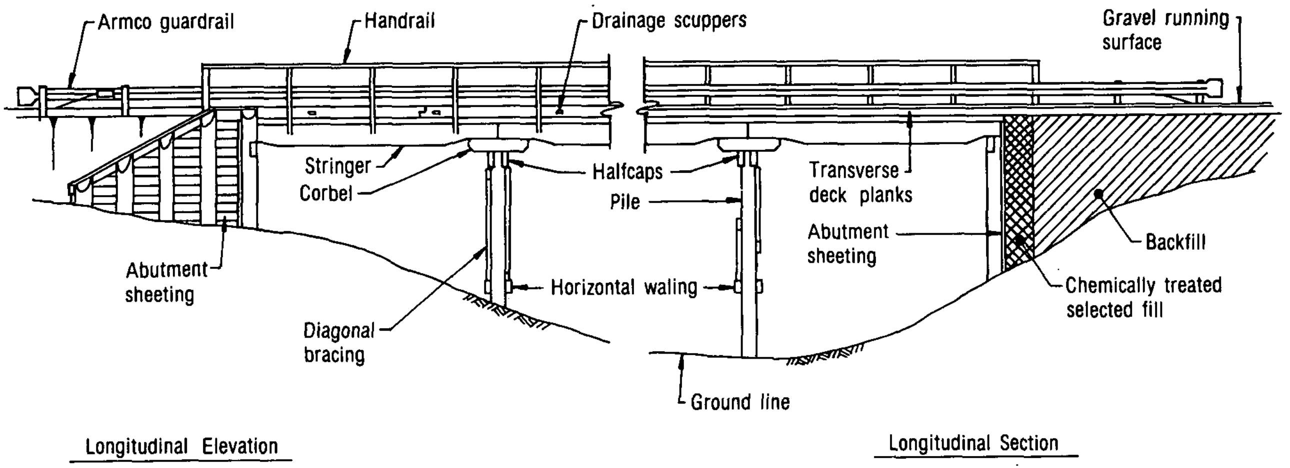

FIGURE 4 - LONGITUDINAL ELEVATION AND SECTION OF STANDARD TIMBER BRIDGE

3.1.2 Superstructure

The main structural members in the superstructure are the round timber stringers. Standard spans of 6.0m and 7.5m are used and stringer dimensions for each of these are as follow:

	6.0m Span	7.5m Span
Min crown diameter	520mm	520mm
Min mid-span diameter	530mm	580mm
Max butt diameter	600mm	650mm

degree of continuity for live loads. Account is taken of this in the design of the halfcaps by distributing maximum live load effects to both halfcaps in the ratio of 2/3 : 1/3. The mating faces of round timber corbels and stringers are dressed to provide a minimum seating of 200mm true wood. This requires a scarf to be cut at each end of the stringers which should be kept as shallow as possible to avoid creating a notch at the point of maximum shear. The slope of the splay on the scarf should be no greater than 1 in 3 as shown at Figure 6. The upper face of stringers is dressed to provide a seating for the decking planks and this usually varies in width from 200mm to 250mm.

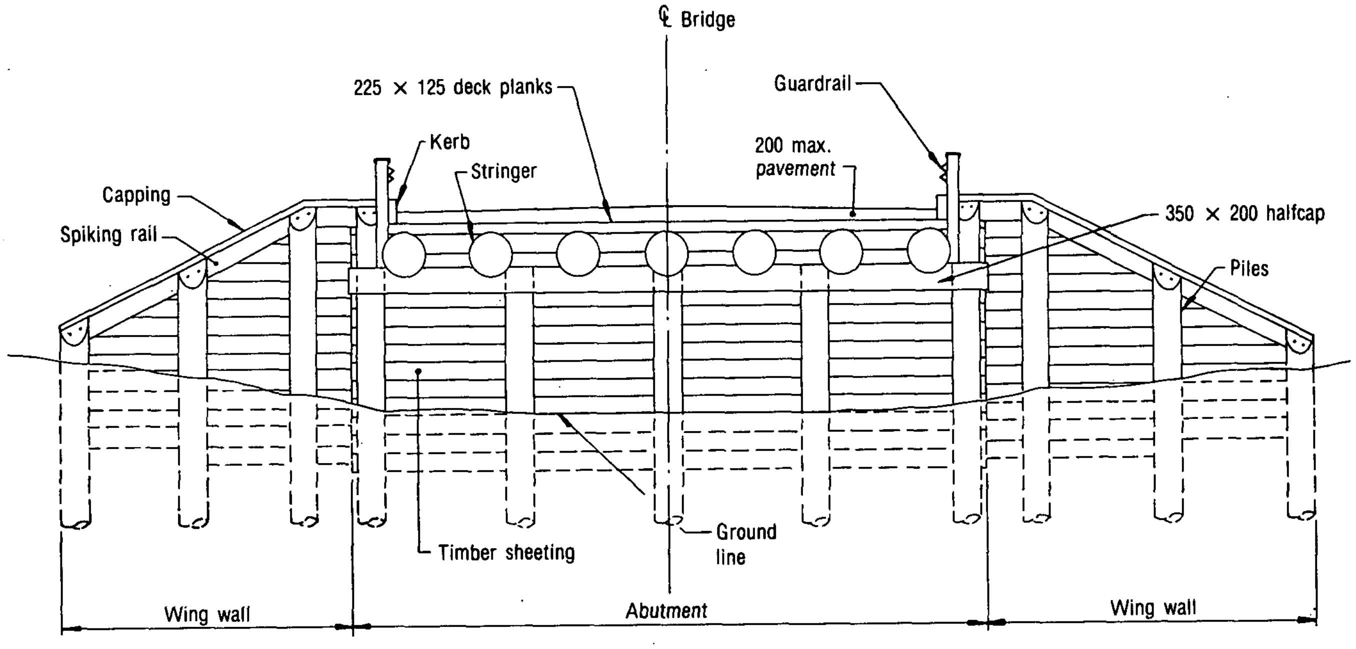

FIGURE 5 - ELEVATION OF BRIDGE ABUTMENT

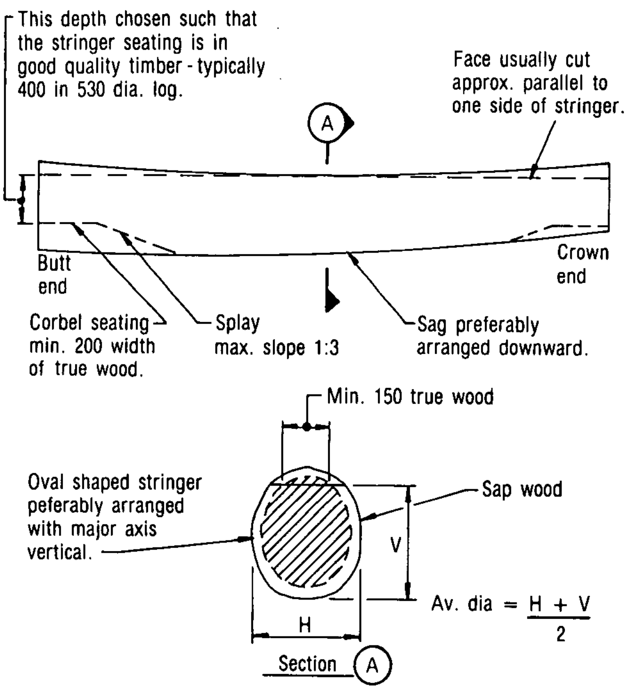

FIGURE 6 - FACINGS AND SEATINGS FOR ROUND TIMBER STRINGERS

3.1.3 Decking

Transverse deck planks 225mm x 125mm in section are fixed to the timber stringers with 225 mm long spikes. If traffic is allowed to run directly on the timber deck these spikes quickly work loose and the decking becomes unserviceable. The deck is therefore surfaced with 150mm of waterbound gravel topped with a thin bituminous spray seal. The gravel suface distributes individual wheel loads and avoids the 'hammer' effect of vehicles running directly on the timber. As the timber deck planks dry out they shrink and gaps open up between individual members. These gaps lead to a loss of gravel and eventual breaking up of the road surface. The standard way of preventing such gravel loss was to provide thin timber battens across each joint, nailed to one side but these battens were expensive to install and were prone to rot. More recently timber decks have been covered with a geotextile fabric prior to placing the gravel surface and this has proved cheaper and equally effective.

A 300 x 150 timber kerb is provided along each edge of the deck. This is seated on top of the deck planks and bolted at intervals to the timber stringer to provide edge stiffness as well as retain the gravel surface as shown in Figure 7. Timber posts are bolted to the side of the kerb and to the outside stringer to provide support for a flexible guardrail and handrail.

3.2 Timber Properties

The main requirements for bridge timber are that it is:

- available in large sizes.
- resistant to deterioration by the action of fungi and termites.
- resistant to fire.

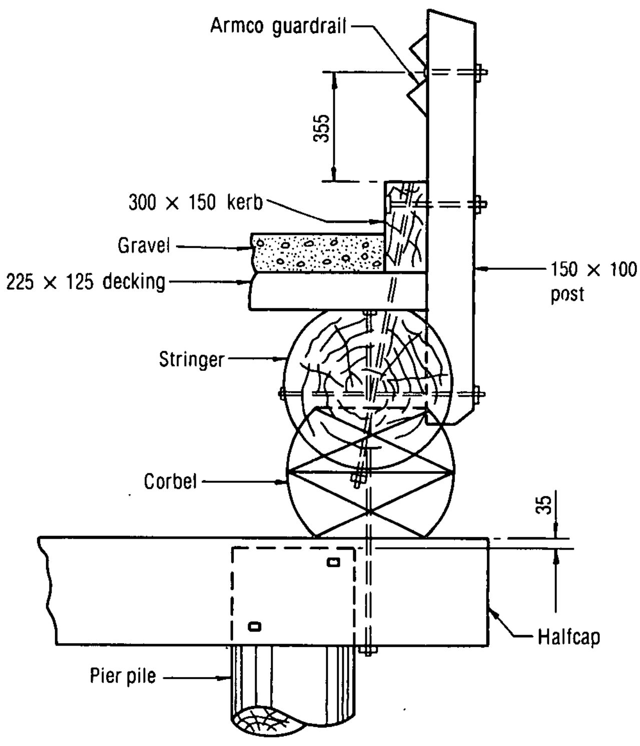

FIGURE 7 - DETAILS OF KERB AND STRINGER BOLTING

3.2.1 Timber Species

The four species of timber native to Western Australia which meet these criteria are:

Jarrah - Eucalyptus marginata
Wandoo (White Gum)- Eucalyptus wandoo
Blackbutt, W. A. - Eucalyptus patens
Tingle, Yellow - Eucalyptus guilfoylei

Jarrah is by far the most widely used though considerable quantities of Wandoo were used in the past. Blackbutt and Yellow Tingle are less readily available. Another timber used in the past was Karri (Eucalyptus diversicolor) but this is less durable and very susceptible to termite attack.

3.2.3 Allowable Stresses

The allowable design stresses for the above species are listed in Table II. The design of longitudinal stringers is normally governed by strength in bending and the allowable stresses in round timbers are some 12.5% greater than these permitted in sawn timber to allow for the smaller influence of natural defects on the strength of round timber.

In Table II a distinction is made between design stresses and overload stresses to take account of the time-dependent properties of timber. Design stresses are used for normal design loads whereas overload stresses are used to determine the capacity of a bridge to carry infrequent overloads - mainly abnormal vehicles moving with a special single trip permit.

In determining stresses in timber bridge members the normal impact allowance for moving vehicles is neglected.

TABLE II

MECHANICAL PROPERTIES FOR WESTERN AUSTRLAIAN TIMBERS

ALLOWABLE STRESS MPa						
Timber Species	Jarrah, WA Blackbutt		Karri, Yellow Tingle		Wandoo	
Stress	Design	Overload	Design	Overload	Design	Overload
Bending in Sawn Timber	11.0	16.5	13.8	20.7	16.5	24.8
Bending in Round Timber	12.4	18.6	15.5	23.3	18.6	27.9
Tension in Sawn Timber	11.0	16.5	13.8	20.7	16.5	24.8
Tension in Round Timber	12.4	18.6	15.5	23.3	18.6	27.9
Shear	0.8	1.2	1.4	2.1	1.7	2.6
Bearing in Parallel to Grain	8.3	12.5	13.1	19.7	15.2	22.8
Bearing Perpendicular to Grain	3.4	5.1	4.8	7.2	6.2	9.3
Elastic Modulus E (GPa)	11.7		14.5		16.5	
Density Green (kg/m^3)	1 120		1 200		1 280	

3.3 Construction Requirements

3.3.1 Sawn Timber

Sawn timber is specified on the basis of AS2082-1979. Timber exhibits greater shrinkage away from the heartwood which causes individual members to bow. Quarter sawn timber tends to bow in both plan and elevation whereas backsawn timber only bows in elevation. Timber decking is therefore specified to be backsawn and placed sapwood uppermost so that the bow is restricted to the vertical plane and deck planking can be readily pulled down at the ends by spikes. The more durable timber is also in contact with the stringers so that the onset of rot at the interface is delayed. These details are illustrated in Fig. 8. Timber in deck planks is required to be Structural Grade No 1.

Halfcaps are highly stressed structural members and they are specified as Structural Grade No 2. They are fixed with sapwood facing outwards so that any bow can be corrected by pulling in the ends and so the more durable timber is located on the pile seating.

3.3.2 Round Timber

The Department has its own specification for untreated round timber and this defines permissable defects, and permissable tolerances on straightness, taper, diameter and length. Slow grown round timber is preferred for bridges as this has minimum sapwood and the true wood is more resistant to biological deterioration. Such timber is becoming increasingly hard to obtain and some form of preservative treatment may have to be adopted in the future to extend the life of present day timber. To obtain maximum strength from a log the seating for the deck planks is kept as narrow as possible (200mm to 250mm) and if the log is bowed it is placed with the sag downwards so the maximum depth can be retained at mid-span.

3.3.3 Shrinkage of Timber

Allowance must be made for the shrinkage of timber to ensure proper long term support at seatings. Techniques adopted include slotting the bottom hole in handrail posts and holes through piles used for the bolts securing halfcaps. It is also necessary to periodically tighten the nuts on bolts securing stringers to corbels and halfcaps, and kerbs to stringers.

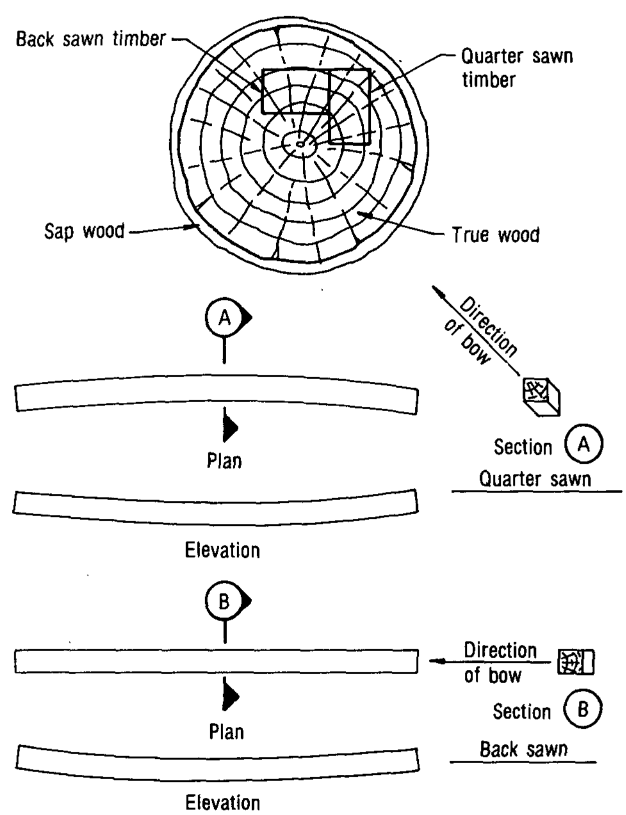

FIGURE 8 - TYPES OF SAWN TIMBER

3.4 Design Practice

The designs used for timber bridges have been standardised for a number of years but it is sometimes necessary to check the load capacity of existing structures and the following notes are particularly relevant to such load rating calculations.

3.4.1 Deck Planks

Deck planks are analysed as continuous beams supported by the timber stringers. They are designed for self-weight, superimposed dead load such as gravel pavement, and vehicle live load. Individual wheel loads are assumed to act on individual planks without distribution to adjacent planks.

3.4.2 Round Timber Stringers

Round timber stringers are designed for self-weight, superimposed dead load from the deck and vehicle live load. Vehicle loads are distributed to the stringers by the transverse deck planks and the proportion of vehicle load carried by an individual stringer is calculated using a torsion free grillage analysis which takes account of both the transverse stiffness of the deck planks and the longitudinal stiffness of the individual stringers. Distribution factors for stringers typically vary from 0.20 to 0.35 of the vehicle loading, depending on the location of the vehicles across the width of the deck.

In calculating the strength of individual stringers an idealised circular section is used having an average mid-span diameter of

$$\frac{H + V}{2}$$

where H and V are defined in Figure 7. When calculating the section modulus of the stringer the average diameter is reduced by 25 mm to allow for eventual deterioration of the sapwood as no preservative treatment is applied.

4. RECENT DEVELOPMENTS IN DESIGN

4.1 Reinforced Concrete Decks

The part of a timber bridge most prone to deterioration is the timber deck and in the past it was standard practice to redeck a bridge at least once during its life. The following factors have now made redecking uneconomic:

(i) heavier and faster traffic causing deck planks to work loose;

(ii) less durable timber now available making more frequent redecking necessary;

(iii) sawn timber deck planks more expensive to replace.

To overcome these problems some recent timber bridges have been constructed with reinforced concrete decks instead of the standard timber plank decks. The advantages of the reinforced concrete deck are:

(i) it is not susceptible to rot and termite attack;

(ii) the structurally stiffer deck provides better distribution of load to stringers;

(iii) it is relatively waterproof so that timber stringers and substructure are protected from deterioration.

4.1.1 Concrete Deck on Timber Stringers

Figure 9 shows a design where the timber deck planks are replaced with a 150 mm thick reinforced concrete slab. The slab is cast on permanent formwork consisting of Bondek metal decking which is nailed to the timber stringers. This design retains the traditional appearance of a timber bridge and placing the reinforced concrete deck is a simple operation which can be easily handled by a timber bridge gang.

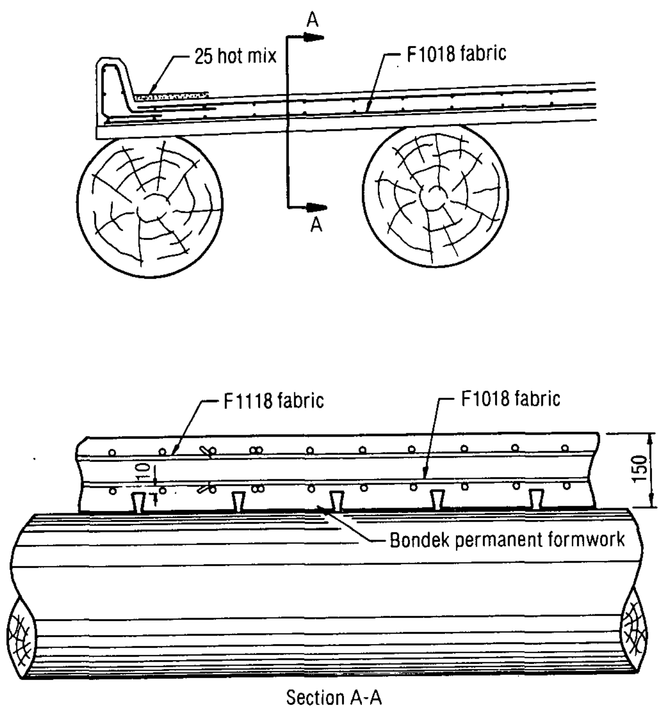

FIGURE 9 - CONCRETE DECK ON TIMBER STRINGERS

4.1.2 Concrete Deck Cast Direct on Timber Piles

Figure 10 shows an alternative design where a 300 mm thick reinforced concrete deck is cast directly onto timber piles. This is a more radical departure from traditional timber construction and is identical to a reinforced concrete flat slab bridge except that timber piles are substituted for the more usual steel or concrete piles. At sites where round timber piles are readily available it can provide a very economical form of construction. Typical spans are 6.0 m to 7.5 m.

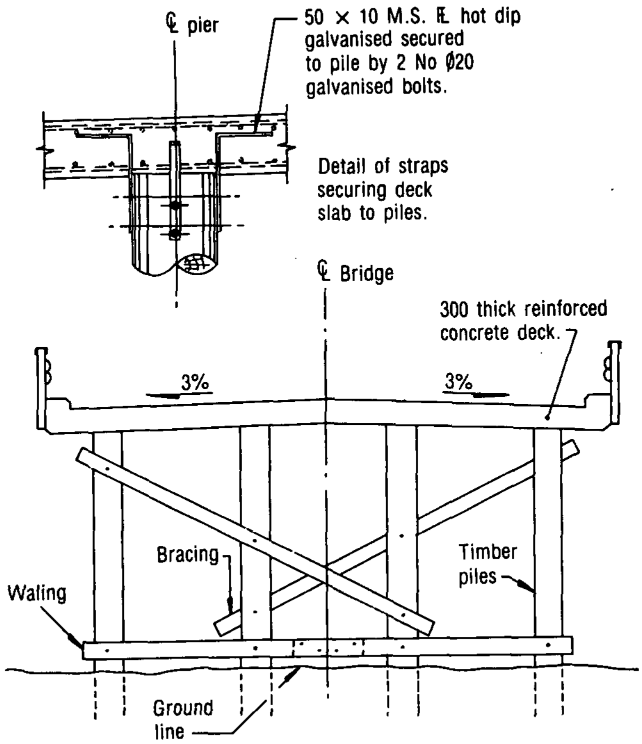

FIGURE 10 - CONCRETE DECK ON TIMBER PILES

4.2 Plywood Decks

Plywood panels have recently become available in thicknesses up to 200 mm and some road authorities are experimenting with this as an alternative deck material It has not so far been used by the Main Roads Department in Western Australia but could be used at remote sites where concrete is not readily available. The plywood can be pressure treated against biological attack and does not suffer from significant shrinkage. Its behaviour under traffic would need to be evaluated before using it extensively. Treated plywood could also be a useful replacement for sawn timber in the sheeted abutments.

5. MAINTENANCE

Timber used for the older bridges in Western Australia has proved to very durable and a life of fifty to sixty years was quite common. Since 1950 the availability of slow grown and highly durable timber has declined and some bridges built during the 1950's and 1960's are already experiencing serious decay. Because of their high durability the older bridges seldom suffered structural failure but generally became substandrad because of poor road geometry. It was therefore normal to replace such bridges on a new alignment or with better geometry rather than repair them. Now that timber bridges are suffering faster structural decay more resources are having to be allocated to major maintenance.

5.1 Forms of Deterioration

Deterioration of timber bridges mainly occurs due to biological attack by fungi, termites and marine borers. The structural components most affected are the deck, the sheeted abutments and the piles just below ground line.

5.2 Maintenance of Timber Decks

Timber decks deteriorate due to fungal attack (rot) caused by the presence of moisture in the gravel pavement. As well as causing rot in deck planks the moisture penetrates around the spikes and into the top of the stringers where further rot causes the spikes to gradually work loose. The process is accelerated by poor drainage of the deck due to blocked scuppers. The line of rot along the seating for the deck planks on the top of the stringers makes it difficult for new spikes to hold new deck planks in position. Because of this the Main Roads Department have developed a technique for repairing decks with concrete overlays.

5.2.1 Concrete Overlays

Where the running surface of a bridge deck continually breaks up and potholes under traffic due to loss of gravel through the timber deck but the bridge is otherwise sound it is now standard practice to upgrade the bridge with a concrete overlay. The gravel paving is removed from the timber deck, any broken deck planks are replaced, the remaining planks are pulled down onto the stringers with additional spikes and a reinforced concrete overlay is cast directly on the timber deck. Details of a typical concrete overlay are shown in Figure 11 and Pressley[1] has described the technique in detail. Expansion joints were originally provided over bridge piers at every fourth span but the spacing was gradually increased until today when overlays up to 80 m in length have been constructed with no expansion joints. A groove is cut with a diamond saw over every pier, however, to act as a crack control joint. Some of the expansion joints on early overlays have since failed by the overlay peeling away from the timber deck. These failures have been repaired by cutting back the overlay 1 m on either side of the joint, lapping new reinforcing mesh over the exposed original mesh, and making the overlay continuous over the former joints.

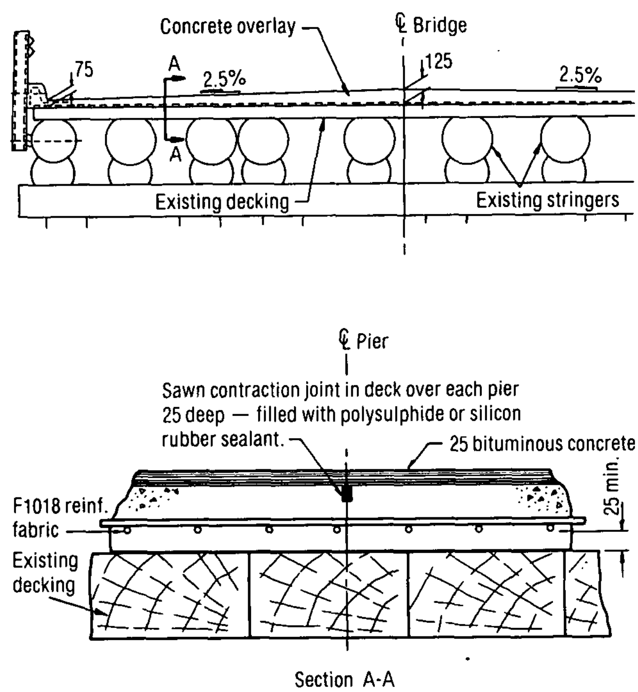

FIGURE 11 - DETAILS OF CONCRETE OVERLAY

5.3 Maintenance of Timber Piles

In recent years increasing numbers of timber piles have failed due to rot at or just below ground line. Unless detected during a routine inspection failure only becomes apparent when the deck settles due to crushing of the rotted timber in the pile. The method of repair is to either drive another pile alongside (usually a steel section) or replace the rotted section of pile with a reinforced concrete splice as shown in Figure 12. These methods of repair are expensive and various techniques are now being investigated for the insitu treatment of piles with preservative to stop further decay before failure occurs. Methods being tried include wrapping with fungitoxic bandages and injecting diffusible toxic compounds of chemicals such as copper, fluorine and boron into holes drilled into the piles at ground line.

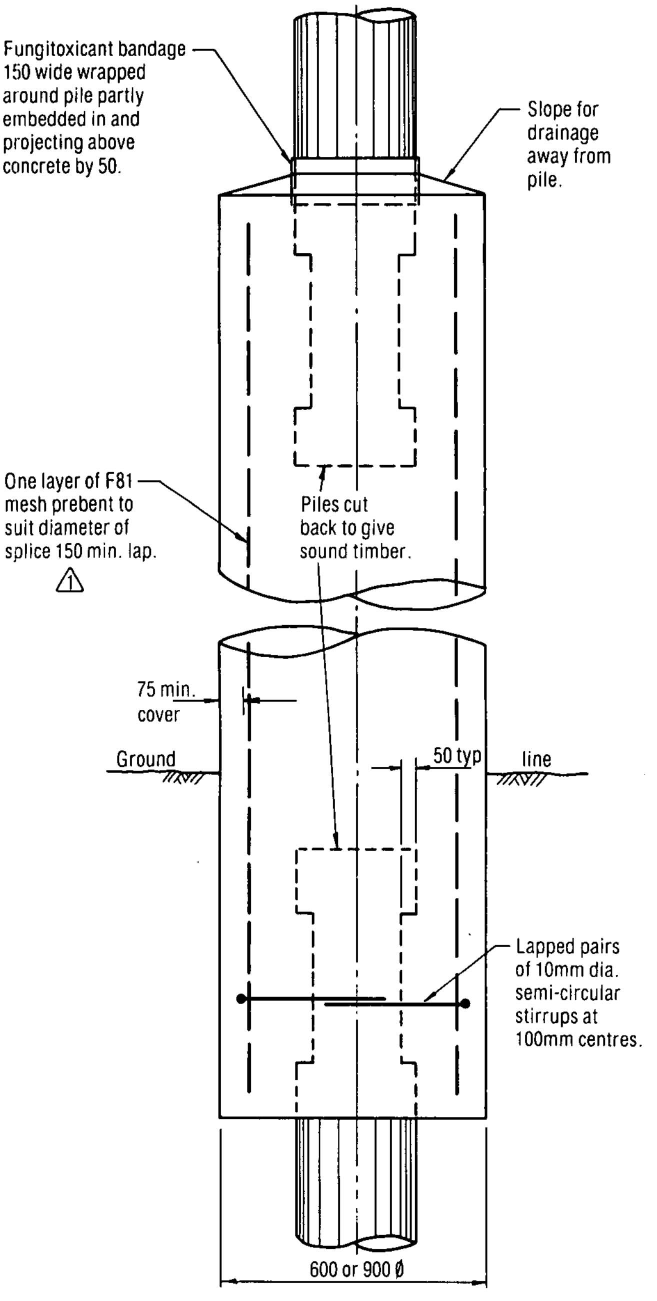

FIGURE 12 - CONCRETE SPLICE FOR TIMBER PILES

6. CONCLUSION

Timber has proved a practical and economic material for the construction of bridges in the South West of Western Australia for a period of some one hundered and fifty years and present indications are that it will continue to be used in the future.

Now that less durable timber is being used some form of selective preservative treatment is justified for the timber members most prone to decay.

Because of the high replacement cost of timber bridges there is a need to invest more engineering resources into developing new techniques for the maintenance and strengthening of existing bridges.

7. ACKNOWLEDGEMENTS

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8. REFERENCES

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